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MISCELLANEOUS PAPER NO. 6-737

PARTIALLY COMPACTED WEIGHT OF CONCRETE AS A MEASURE OF WORKABILITY

by

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August 1965

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CORPS OF ENGINEERS
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FOREWORD

This paper was prepared at the request of the Program Committee for the Fall Convention of the American Concrete Institute, Cleveland, Ohio, 5 November 1965. It was submitted to and approved by the Chief of Engineers for presentation and publication by first indorsement dated 12 August 1965 to a letter dated 14 July 1965 subject: Approval of Paper for Presentation.

The work on which the paper is based was conducted at the Concrete Division of the U. S. Army Engineer Waterways Experiment Station under the direction of Mr. Thomas B. Kennedy and Mr. Bryant Mather. Staff members actively concerned with the work included Messrs. W. O. Tynes, K. L. Saucier, and W. B. Lee. The reports on which the paper is based were prepared, respectively, by Mr. Mather and by Messrs. Mather and Saucier.

Directors of the WES during the investigation, the preparation of the reports, and of this paper were Colonel Edmund H. Lang, CE; Colonel Alex G. Sutton, Jr., CE; and Colonel John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

Partially Compacted Weight of Concrete as a Measure of Workability[1,2]

by
Bryant Mather[3]

In the ACI Standard Recommended Practice for Selecting Proportions for No-Slump Concrete as reported by Paul Klieger for Subcommittee 2 of Committee 211, one of three suggested methods for measuring consistency of concrete is the compacting-factor procedure as described in British Standard 1881 (fig. 1). This test is based on the assumption that the drier the consistency, the greater will be the void volume of an uncompacted sample. Concrete is placed in the upper hopper, allowed to fall into the second so as to achieve a given state of looseness, then allowed to fall into a 6-in. diameter, 12-in. high cylindrical mold. The struck-off net weight before additional compaction, expressed as a ratio of the fully compacted weight of concrete filling the same mold, is the compacting factor. There is an approximate relation between compacting factor and slump, as is indicated in fig. 2, which also is taken from the ACI 211 Standard. Apparatus for field use has been developed in which the weighing device is incorporated (fig. 3). As a part of Item 619, "Investigation of Placeability of Concrete," of the Engineering Studies Program of the Corps of Engineers, the U. S. Army Engineer Waterways Experiment Station

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[1]Prepared for presentation at Research Session of American Concrete Institute Convention, Cleveland, Ohio, 5 November 1965.

[2]Based on "Investigation of Partially Compacted Weight of Concrete as a Measure of Workability," USAEWES Technical Report No. 6-598, Report No. 1, "Preliminary Tests" (April 1962) and Report No. 2, "Tests of Large-Aggregate Concrete" (August 1963).

[3]Research Civil Engineer, Concrete Division, U. S. Army Engineer Waterways Experiment Station, Jackson, Mississippi.

was authorized to make studies to determine if an approach, based on the compacting factor principle, could be developed for mass concrete that would be superior to the present practice of controlling consistency by making slump tests on samples wet screened through the 2-in. sieve.

The compacting factor apparatus constructed for use in our initial studies is shown in fig. 4. In the first tests a comparison was made of the uncompacted unit weights of samples of two mixtures that were, in one case, dropped into the mold through the two hoppers of the compacting-factor apparatus and, in the other, discharged into the mold directly from a tilting mixer. This experiment was based on the assumption that both hoppers of the apparatus could be eliminated if concrete were made repeatedly available in a comparable state of looseness at a given distance above the mold. The average unit weight of the uncompacted concrete in the mold was slightly greater when the mold was filled directly from the mixer discharge than when the mold was filled by allowing the concrete to drop through the two hoppers. For one mixture, having a slump of 1 to 1-1/2 in., the compacting factors ranged from 0.805 to 0.870 and for the other mixture, which had a slump of 2-1/2 to 2-3/4 in., the range in compacting factor was 0.849 to 0.945.

In the second series of tests a single mixture of nominal 2-in. slump was used with seven different water contents so as to give slumps from 0 to 8 in. The water-cement ratio for 2-in. slump was 0.54; at 0 slump it was 0.49; at 8-in. slump it was 0.67. The range of water content-change was from 23 lb/cu yard less to 61 lb/cu yd more than the nominal amount that gave the 2-in. slump. The compacting factor (fig. 5) for the nominal 2-in. slump mixture was 0.860; when the water content was least, this dropped to 0.790; when

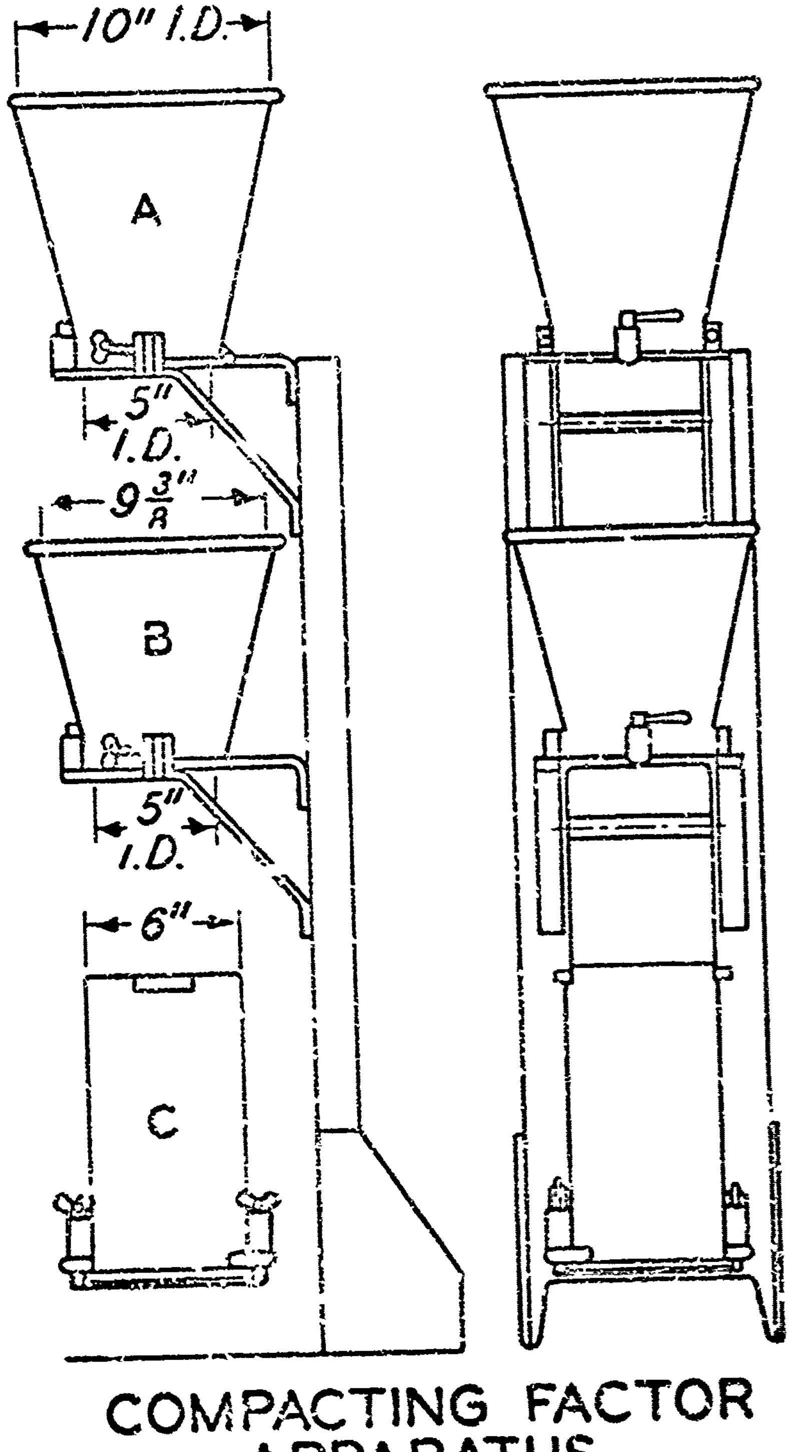
the water content was most, it was 0.966. The more significant feature of the results of this study, in terms of what it suggested about possible field application to mass concrete construction, was the relationship found between consistency (or slump, or water content) and net uncompacted weight (fig. 6). In addition, some attention was given to the degree of heaping of the material as the container was overfilled with uncompacted concrete. This, in effect, was a study of the angle of repose. Fig. 7 indicates these results expressed as a relation of weight removed on strike off - obviously the steeper the angle of repose, the higher the cone of heaped concrete and hence the greater the weight of concrete struck off. The observations suggested, for the mixture under study, that, were it desired to hold the workability at a consistency -- water content -- slump -- such as this mixture possessed when it had a slump of 1-1/2 in., then this would be obtained if it were required that there be a minimum value for weight of concrete struck off; i.e., a maximum angle of repose. It was concluded, however, that for a test for uniformity of workability of mass concrete when repeated batches of similarly intended composition were involved and the primary batch-to-batch variation could be assumed to be due to unintentional changes in water content, the struck-off uncompacted weight could be taken as a parameter for control purposes, at least so long as the desired workability was somewhere in the range represented by a slump of 3 in. or less.

With this background, the compacting factor apparatus, as such, was set aside, and studies using 6-in. aggregate concrete were begun. For this work a 3-1/2-cu ft unit-weight measure having an inside diameter of 20-3/4 in. was used as the mold and was placed on a 1000-lb capacity scale.

Approximately 5 cu ft of concrete was allowed to fall into this mold from a 1/2-cu yd bottom-dump bucket with a 15-in. square opening positioned 3 ft above the mold. The heaping weight, weight after strike-off, and compacted weight were recorded (fig 8). Strike-off was accomplished by use of a 3-in. diameter steel shaft. The mixture used contained no cement and initially had 226.5 lb of fly ash and 118.8 lb of water per cu yd. The same 15-cu ft batch was used repeatedly, adding water for each of seven successive tests until the water content had been raised until it was essentially double that at the start. These tests were repeated three times. At each test samples were taken, sieved through a 1-1/2-in. sieve, and tested for slump, and sieved through a No. 4 sieve and dried out to determine water content of mortar. A period of 3 to 4 hr was involved in making each series of tests. From the test results it will be noted that all the recorded weights -- heaping, struck-off, and consolidated -- and also the compacting factor, reached a maximum when the mortar water content was about 12 percent and then declined. These relations are shown in fig. 9 for the three batches separately for heaped weight before strike off. A similar pattern is shown in fig. 10 for struck-off uncompacted weight. The numbers shown beside the data points are results of slump tests. The maximum is achieved at a slump between 1-1/2 and 3 in. These results indicate that at low water content the loose concrete contains much air because it is dry and harsh but does not heap high because it is crumbly and poorly cohesive. As water is added, it becomes softer and more cohesive, thus reducing the air space of the uncompacted mass and allowing high heaping. Finally, with more water, the material heaps less as it becomes more able to flow, doesn't compact any better, and becomes lower in unit weight because it contains more water. Fig. 11 shows the compacting factor-slump relation for these tests.

M. R. Smith, who until Monday, 8 November 1965, will be concrete man on the Tarbela Dam Project in West Pakistan, where 3-1/2 million cu yd of concrete will be placed, has developed a direct application of the compacting-factor test that he regards as better than slump. ~~and which does not require wet screening~~. The device he built involves one hopper that discharges into a 1-cu ft container with a top opening about 14 in. square. After strike off and weighing, additional concrete, without large aggregate, is added as the sample is consolidated by internal vibration. Two tests are made on a batch; the weights generally agree within 1%. He finds concrete with a compacting factor of 0.90 good; above 0.94, very plastic, and below 0.84 too harsh to be placed. His data indicate that a compacting factor of 0.84 to 0.94 for his concrete represents about a 1- to 3-in. slump.

I believe that this work points a way to a procedure, involving no manual operations on the concrete, that could detect any batch with either seriously deficient or excessive water content. A bottom-dump container of appropriate size suspended so as to overfill each time the mixer dumped could be weighed through its suspension system and then dumped. A range in weight representing satisfactory concrete could be determined and the plant arranged to reject any batch whose heaped loose weight was found to be outside the established range.

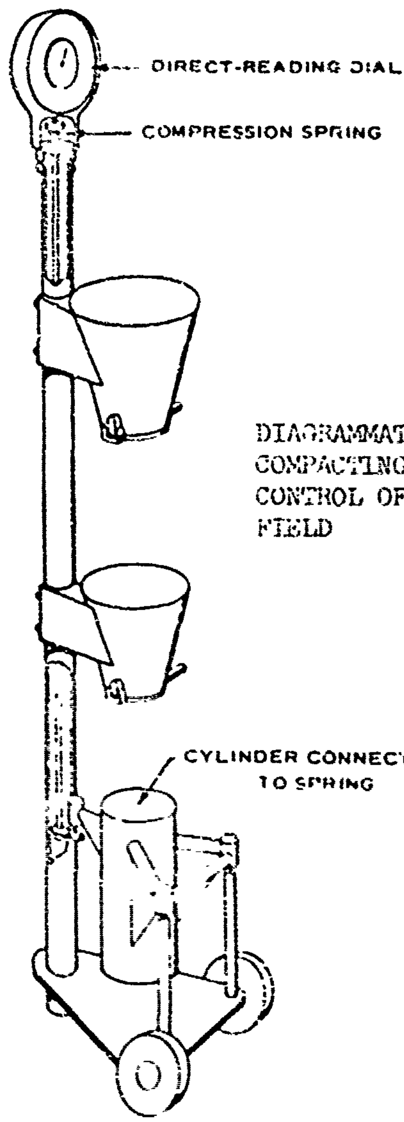


COMPACTING FACTOR
APPARATUS

FIG 1

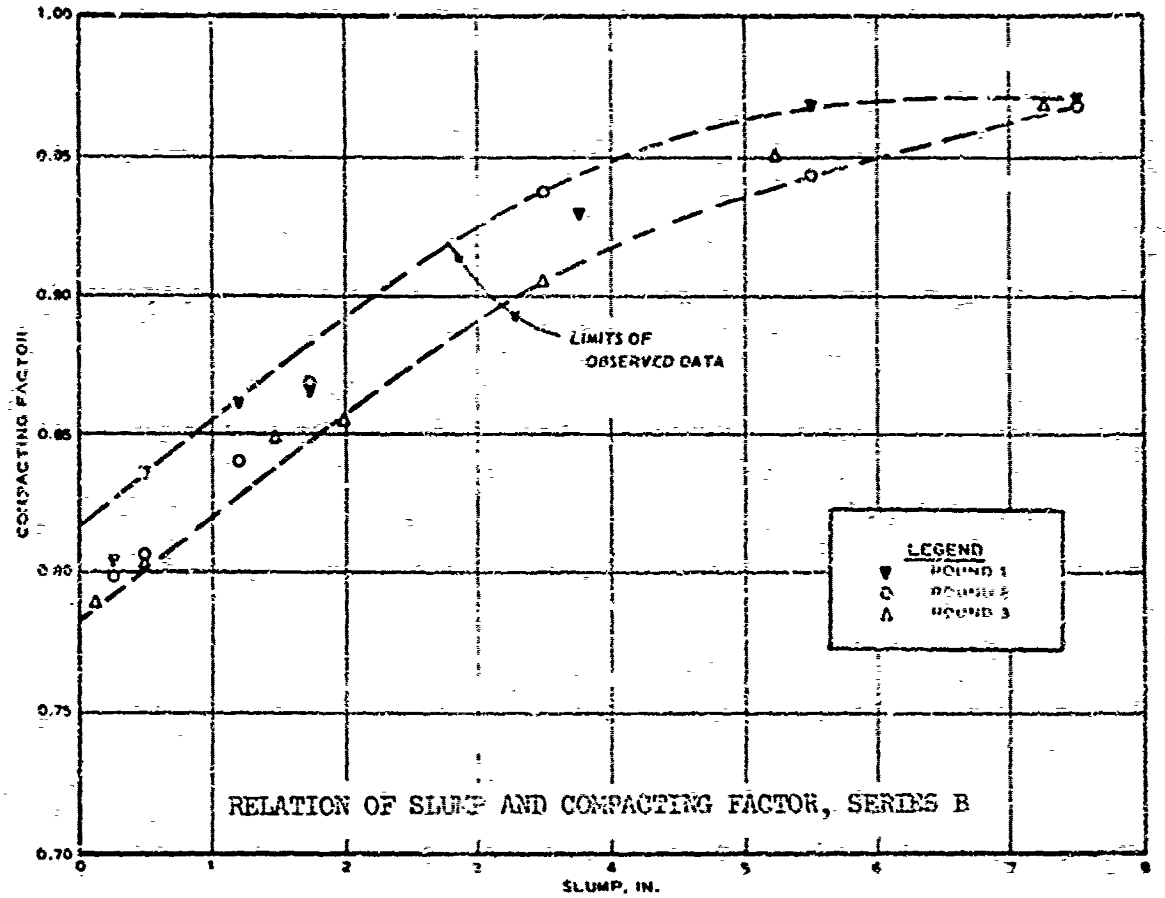
CONSISTENCY	SLUMP IN.	COMPACTING FACTOR, AVERAGE
VERY STIFF	——	0.70
STIFF	0 to 1	0.75
STIFF PLASTIC	1 to 2	0.85
PLASTIC	3 to 4	0.90
FLOWING	6 to 7	0.95

FIG 2



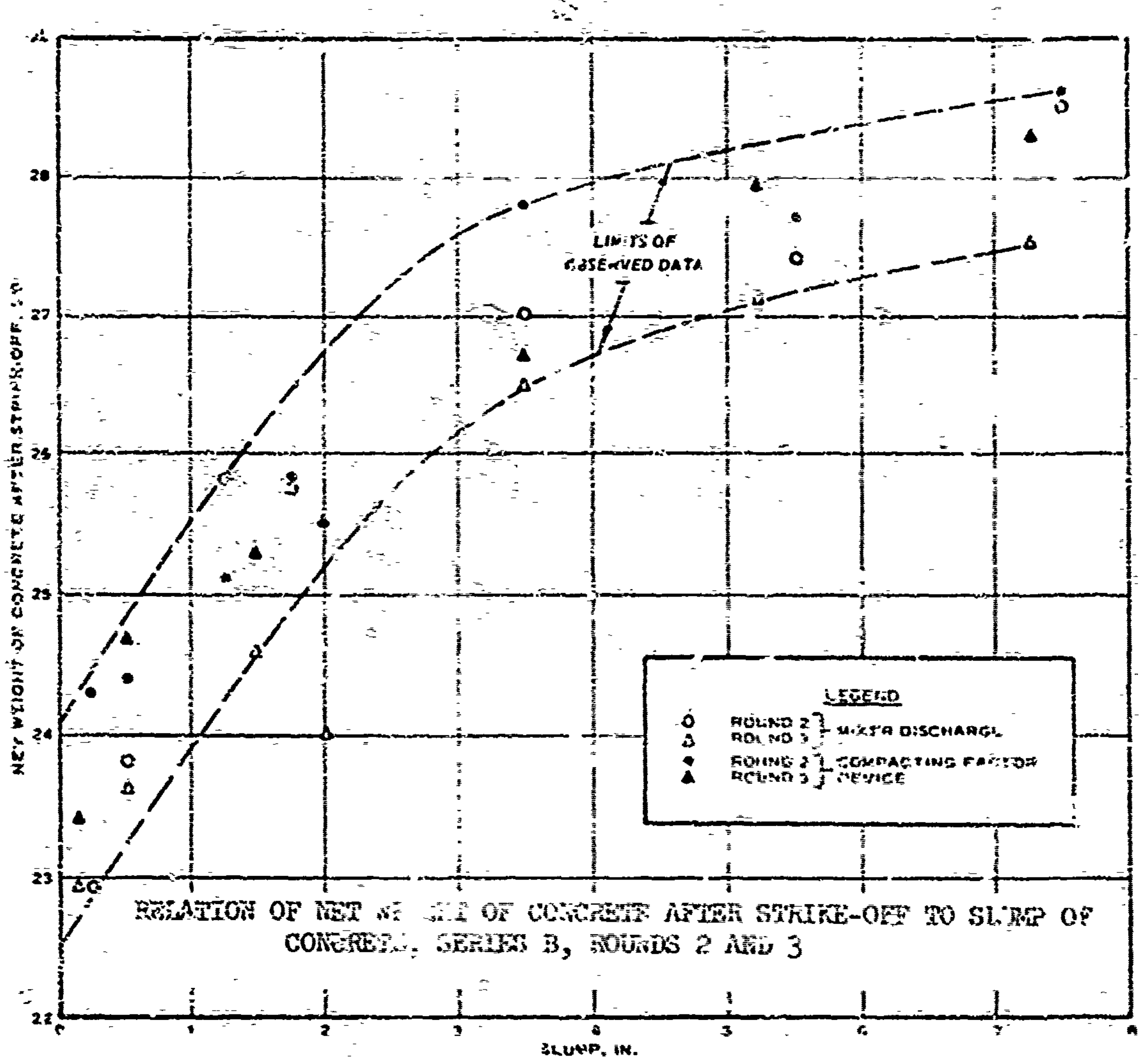
DIAGRAMMATIC SKETCH OF AUTOMATIC COMPACTING-FACTOR APPARATUS FOR CONTROL OF WORKABILITY IN THE FIELD

FIG 3



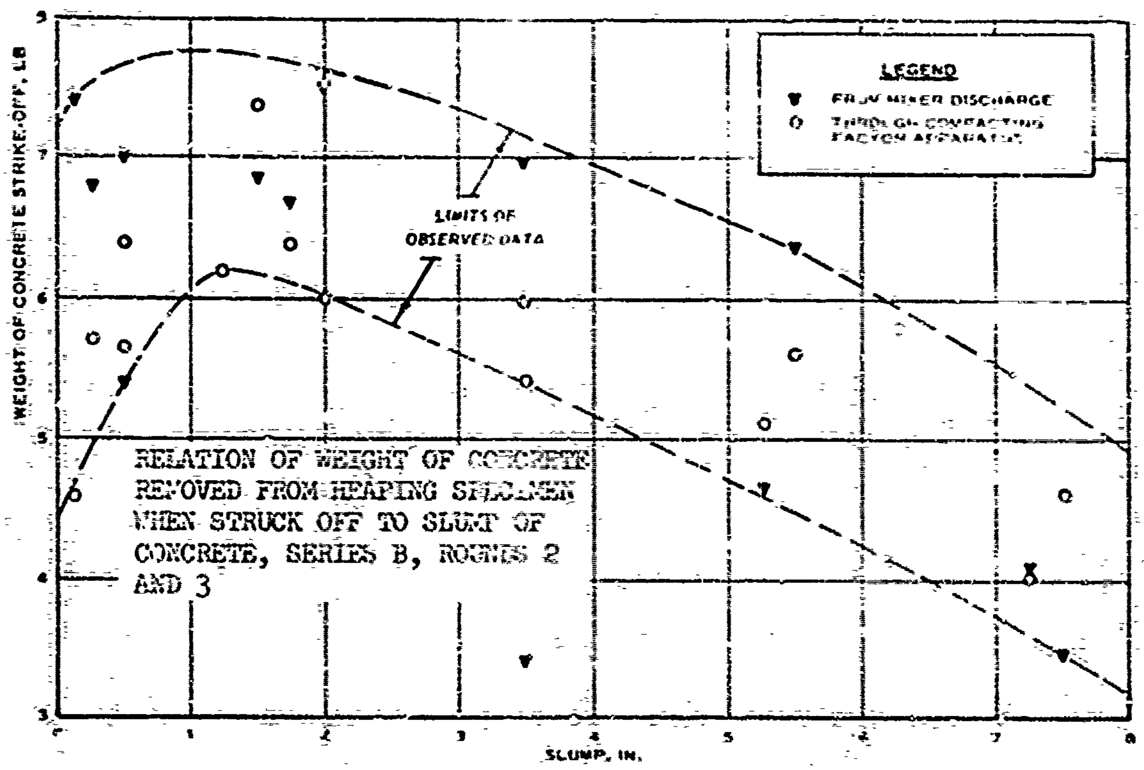
RELATION OF SLUMP AND COMPACTING FACTOR, SERIES B

FIG 5



RELATION OF NET WEIGHT OF CONCRETE AFTER STRIKE-OFF TO SLUMP OF CONCRETE, SERIES B, ROUNDS 2 AND 3

FIG 6



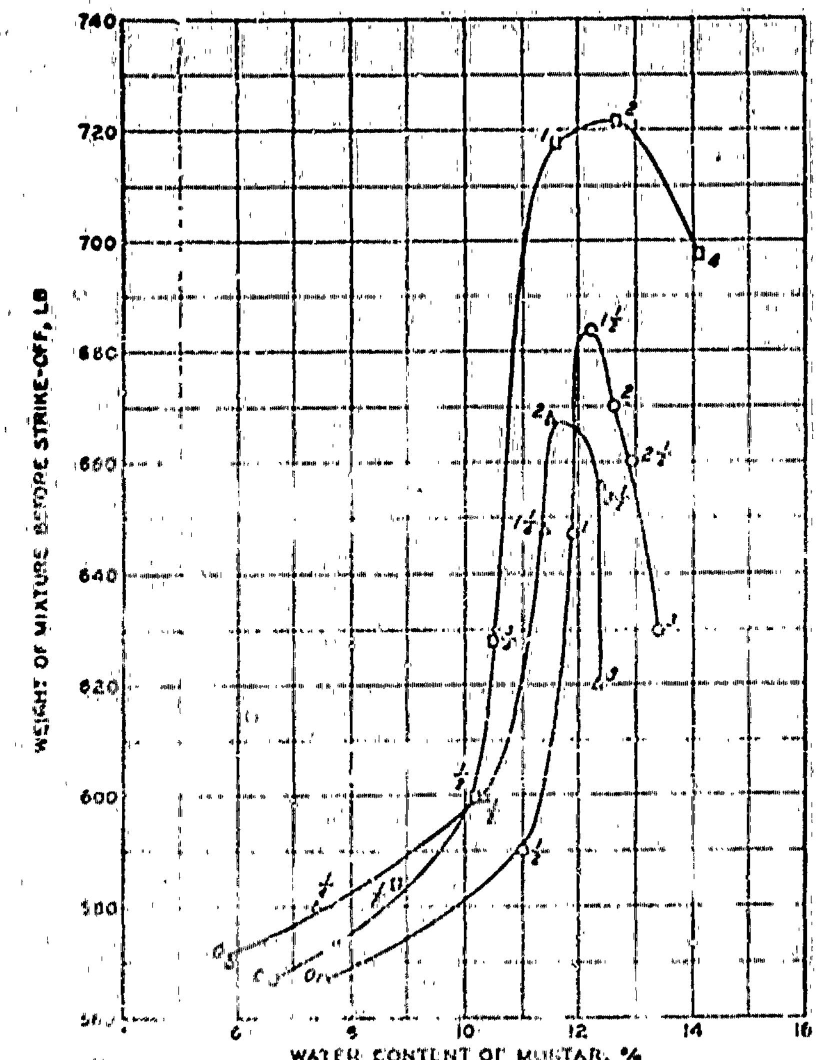
RELATION OF WEIGHT OF CONCRETE REMOVED FROM HEAPING SPECIMEN WHEN STRUCK OFF TO SLUMP OF CONCRETE, SERIES B, ROUNDS 2 AND 3

FIG 7

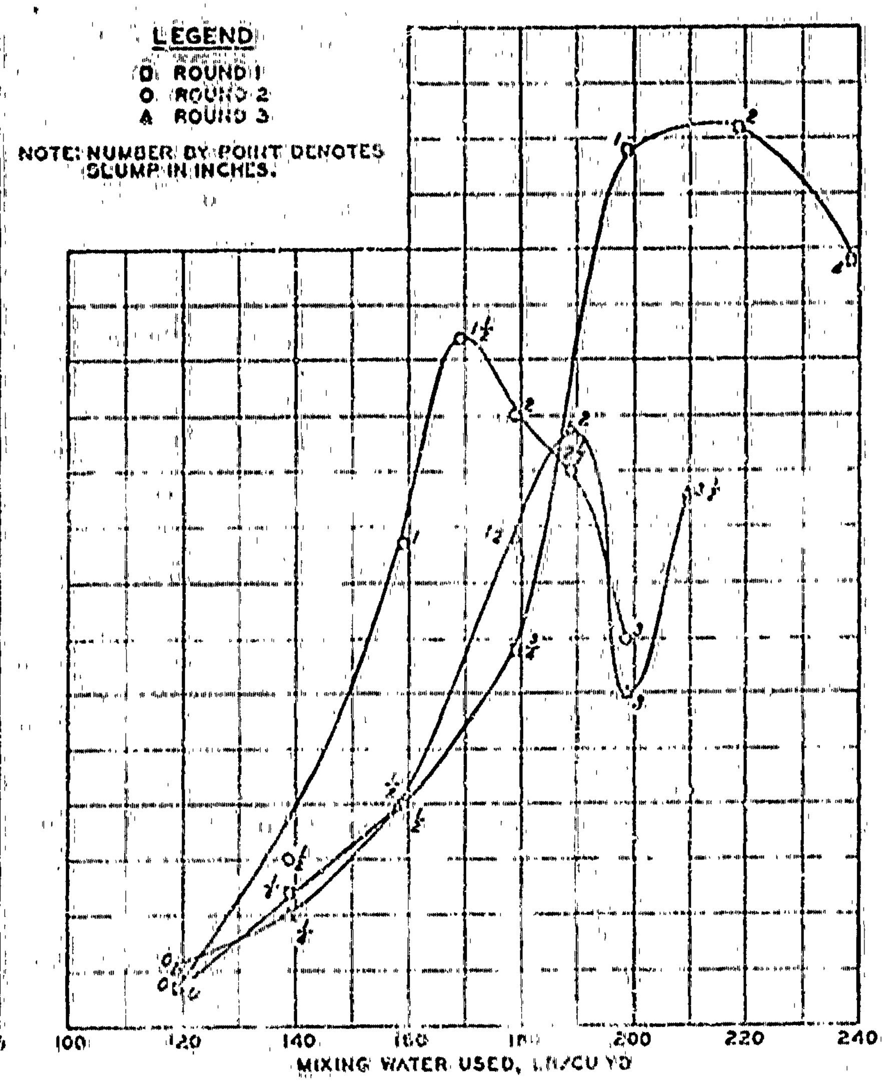
MIXING WATER USED LB/CU YD	MORTAR WATER CONTENT, %	SLUMP IN.	WEIGHT, LB BEFORE STRIKE-OFF	WEIGHT, LB AFTER STRIKE-OFF	WEIGHT, LB FULLY CONSOLIDATED	COMPACTING FACTOR
118.8	6.60	0	567	457	547	0.835
138.8	8.80	1/8	564	453	543	0.834
158.8	10.20	1/2	599	457	549	0.832
178.8	10.50	3/4	628	467	546	0.855
198.8	11.60	1	718	492	552*	0.891
218.8	12.75	2	722*	526*	548	0.960*
238.8	14.10	4	698	516	550	0.938
118.8	7.50	0	567	454	549	0.827
138.8	11.05	1/2	590	476	552	0.862
158.8	11.90	1	647	498	548	0.909
168.8	12.20	1-1/2	684*	520*	553*	0.940*
178.8	12.60	2	670	512	551	0.929
188.8	12.90	2-1/2	660	488	554	0.881
198.8	13.40	3	630	466	555	0.840
118.8	5.95	0	570	460	542	0.849
138.8	7.40	1/4	590	466	546	0.853
158.8	10.30	1/2	600	460	546	0.879
178.8	11.40	1-1/4	648	488	543	0.899
188.8	11.45	2	668*	498	545	0.914
198.8	12.15	3	620	513*	546	0.940*
208.8	12.40	3-1/2	656	496	548*	0.905

* = MAX

FIG 8

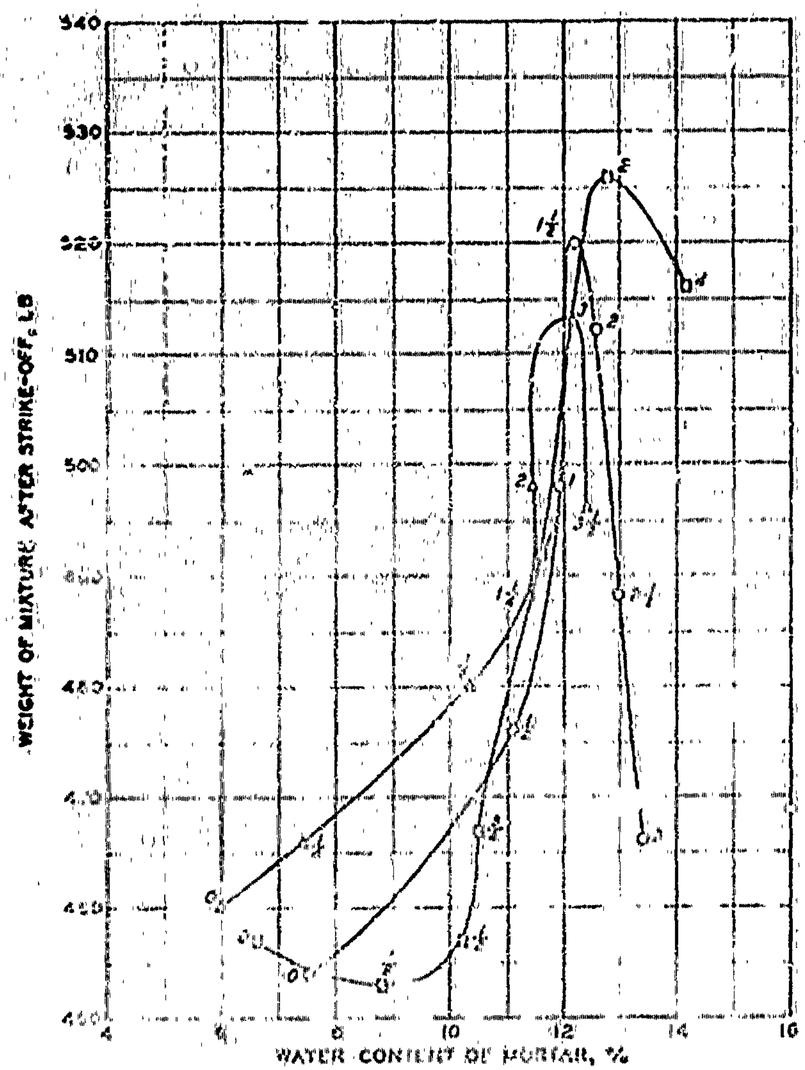


Weight of mixture before strike-off
versus water content of mortar

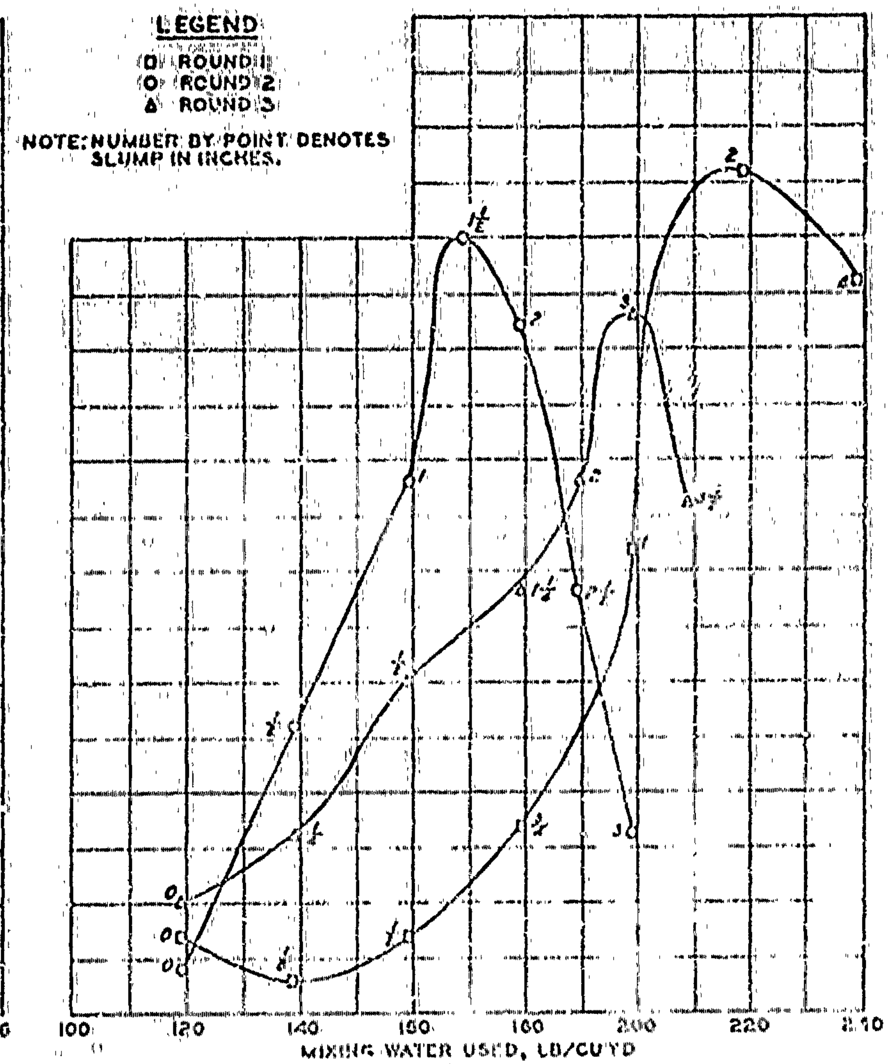


Weight of mixture before strike-off
versus amount of mixing water used

Fig 9

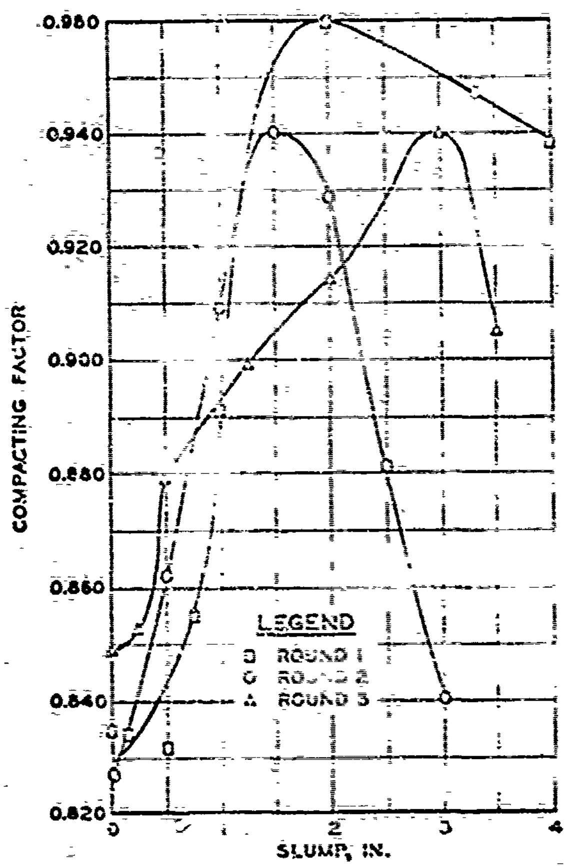


Weight of mixture after strike-off
versus water content of mortar



Weight of mixture after strike-off
versus amount of mixing water used

Fig 10



Compacting factor
versus slump